9 Recent Research

Paper Slides | 9A. | NCHRP 3-95 (Capacity and Operational Effects of Mid-Block Turn Lanes)

James Bonneson, Texas Transportation Institute

Slides — Traffic Operations Issues Related to Unsignalized Intersections on Urban Arterial Streets

Slides — Operational and Safety Effects of Alternative Median Treatments

Paper | 9B. | NCHRP 420 (Impacts of Access Management Techniques)

Jerome S. Gluck, Urbitran Associates

Monday August 14, 2000 – 3:00 PM – 4:30 PM
Track 2 - Technical

Operational and Safety Effects of Alternative Median Treatments

By

James A. Bonneson

Texas Transportation Institute

Background

1. NCHRP Project 3-49
   "Capacity and Operational Effects of Midblock Left-turn Lanes"
2. Operation, Safety, & Access
3. Raised-Curb Median
   Two-way Left-Turn Lane
   Undivided Cross Section

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Overview

Traffic Operations
1. Effect of median treatment
2. Operations model

Traffic Safety
3. Effect of median treatment
4. Safety model

Conclusion
5. Guidelines
6. Additional reading

3

1. Operational Effects

- Delays due to right-turns from arterial.
- Delays due to left-turns from arterial.
- Delays due to high volume on arterial.
- Link spillback & resulting impedance.
- Other: platoons, lane utilization, u-turns...

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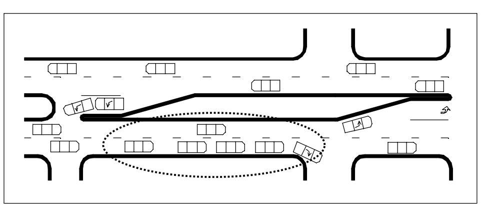
Delays due to right-turns from arterial.



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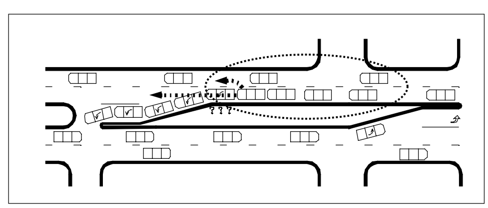
Delays due to left-turns from arterial.



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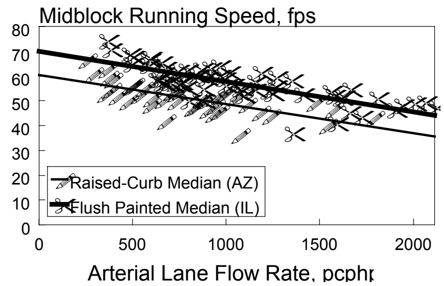
Delays due to high volume on arterial.



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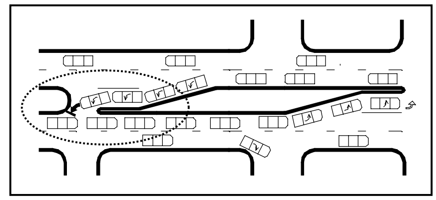
Link Spillback & resulting impedance.



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2. Operations Model

Input Data → TWLTL-MAC → Output Data

Input Data: volume, geometry

Output Data: capacity, delay, queue

Model Calibration Data

- 32 studies in 4 states -- 5-hour study / site
- Data: lane volume, capacity, queue length
- Tape switch sensors & video cameras

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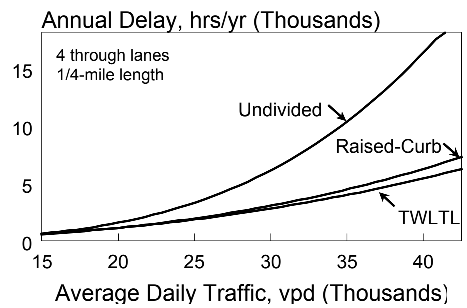
2. Operations Model



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3. Safety Effects

- Raised-median has fewest crashes.
- TWLTL safer than Undivided at higher ADT's.
- Crashes more frequent with:
  1. Higher access point density
  2. Business or Office areas
  3. Parallel parking

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4. Safety Model

Six Regression Equations:

1. Raised-curb in residential & industrial.
2. Raised-curb in business & office.

: : : :

6. Undivided in business & office.

$$A_U = ADT^{0.910}\, Len^{0.852}\, e^{(-14.15\, +\, 0.570\, I_{Park}\, +\, 0.0077\,(DD\, +\, SD)\, +\, 0.0255\, PDO)}$$

Model Calibration Data:

- Omaha, NE & Phoenix, AZ -- 3 years/city
- 6,391 crashes on 189 street segments

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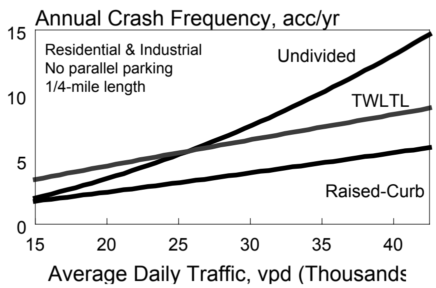
4. Safety Model



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5. Guidelines

Undivided to Raised-Curb Median

ADT	Access Density	Left-Turn Percent					
		0	5	10	15	20	30
17,500	30	U	U	U	U	U	
	60	U	U	U			
22,500	30	U					R
	60						R
27,500	30			R	R	R	R
	60			R	R	R	R
32,500	30		R	R	R	R	R
	60		R	R	R	R	R

5. Guidelines

Sample Calculation:

Existing cross section is undivided.
1760-ft segment length (0.33 miles).
9 active driveways per side.
Arterial ADT is 32,500 vpd.
Left-turn volume is 120 veh/day/drive.

$$\textit{Access pt. density} = \frac{18}{0.33} = 54\ \textit{ap/mi} \quad (\textit{say},\ 60)$$

$$\%\textit{Turns} = (2 \times 9 \times 120) \times \frac{1{,}320}{1{,}760} \times \frac{1}{32{,}500} \times 100 = 5\%$$

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6. Additional Reading

- NCHRP Report 395:
  Capacity and Operational Effects of Midblock Left-Turn Lanes.
- ITE Journal, March, 1998:
  "Median treatment selection for existing arterial streets."
- Transportation Research - A, V. 33(3/4), 1999:
  "Delay to major-street through vehicles at two-way stop-controlled intersections."
- Transportation Research - A, V. 32(2), 1998:
  "Delay to major-street through vehicles due to right-turn activity."

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Overview of NCHRP Project 3-52

Impacts of Access Management Techniques

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4th National Conference on Access Management
August 13-16, 2000
Portland, Oregon

Overview of NCHRP Project 3-52
Impacts of Access Management Techniques

Jerome Gluck, Herbert Levinson

ABSTRACT

This paper presents an overview of NCHRP Project 3-52 -- Impacts of Access Management Techniques. The project classified access management techniques, identified the "priority" techniques, and suggested safety, operation, and economic impact measures. The impacts and benefits of "priority" techniques were quantified based upon an extensive literature review, case studies of good and poor practice, and special field studies. In addition, the salient planning and policy implications were set forth.

ACKNOWLEDGMENTS

This research was performed under NCHRP Project 3-52 by Urbitran Associates in association with Herbert Levinson, S/K Transportation Consultants, and Philip Demosthenes. Jerome Gluck served as principal investigator with major support from Herbert Levinson. Urbitran staff members who made significant contributions to the research include Vassilios Papayannoulis, Greg Haas, Ben Jobes, Robert Michel, Jamal Mahmood, Kathleen Feeney, and Gail Yazersky-Ritzer. Subcontract work at S/K Transportation Consultants was performed by Vergil Stover and Frank Koepke. Philip Demosthenes provided insights from his many years of experience with access management.

State, local, and other agencies were very helpful by providing information on their access management practices and procedures. In particular, the support of the following state departments of transportation in providing accident information is acknowledged: Delaware, Illinois, Michigan, Oregon, New Jersey, Texas, Virginia, and Wisconsin.

The insights, guidance, and suggestions of the NCHRP Project 3-52 panel are greatly appreciated. Panel members included Mr. Arthur Eisdorfer (Chair), New Jersey Department of Transportation (DOT); Mr. Gary Coburn, Ohio DOT; Mr. Ronald Giguere, Federal Highway Administration; Mr. Del Huntington, Oregon DOT; Ms. Denise Kors, British Columbia Ministry of Transportation and Highways; Mr. Kenneth Lazar, Illinois DOT; Dr. William McShane, Polytechnic University; and Mr. Michael Tako, Florida DOT. The support and assistance from Mr. Ray Derr of the National Cooperative Highway Research Program are gratefully acknowledged.

INTRODUCTION

The research objective of NCHRP 3-52 was "to develop methods of predicting and analyzing the traffic-operation and safety impacts of selected access management techniques for different land use, roadway variables, and traffic volumes. The methods to be developed are for use by state departments of transportation, city and county traffic departments, transportation-planning agencies, and private developers." A two-phase research approach was designed to achieve these objectives and to produce practical guidelines for the application, analysis, and selection of various access management techniques.

The first phase identified the various techniques that are available; showed how they can be classified in terms of functional objectives, roadway elements, and likely impacts; and suggested "priority" techniques for further analysis. Likely impacts were extracted based on a literature review, the Research Team's experience, and selected agency surveys. The need for further data collection was identified. First phase efforts concluded with the design of data collection plans that addressed the data voids for the priority techniques.

The second phase focused on the further analysis of priority techniques that included signalized and unsignalized access spacing, median treatments, left turns, separation distances at interchanges, and frontage roads. It involved collecting, analyzing, and synthesizing information obtained from secondary sources to develop methods for estimating impacts; preparing case studies that identified good and poor practices; and performing primary data collection. Findings are contained in a final report and are detailed in a series of technical memoranda.

1. Techniques and Impacts

More than 100 individual access management techniques were identified. These, in turn, were grouped according to policy and roadway design features as shown in Table 1. This system keys techniques to the type of improvements normally applied along highways and access driveways. It is simple to use and understand.

A series of "priority" techniques was identified for detailed analysis. These techniques (1) apply over a large portion of the roadway system, (2) can improve safety, speeds, and emissions, and (3) are generally amenable to measurement. These priority techniques are listed in Table 2. The research effort focused on techniques whose impacts can be measured. Where impacts could not be quantified, case studies identified good and poor practice.

A wide range of possible impacts was identified. These impacts were grouped into four broad categories: traffic operations, traffic safety, environmental, and economics. In reviewing these groups, it became apparent that many impacts are interrelated. For example, emissions largely depend upon traffic volume and speed of travel. Therefore, subsequent analysis for the specific techniques focused on traffic operations (travel times, speeds, capacities) and safety (accident rates). However, economic impacts were also identified where relevant.

Table 1
Recommended Classification System
for Access Management Techniques

I. Policy - Management

a. Access Codes/Spacing
b. Zoning/Subdivision Regulations
c. Purchase of Access Rights
d. Establish setbacks from interchanges and intersections

II. Design - Operations (by roadway features)

a. Interchanges
b. Frontage Roads
c. Medians - Left Turns
d. Right Turns
e. Access/Driveway Location - (Mainly Retrofit -- consolidation, reorientation, relocation)
f. Traffic Controls
g. Access/Driveway Design

Table 2
Priority Techniques Analyzed

1a	Establish Traffic Signal Spacing Criteria
1b	Establish Spacing for Unsignalized Access
1c	Establish Corner Clearance Criteria
1d	Establish Access Separation Distances at Interchanges
2a	Install Physical (Restrictive) Continuous Median on Undivided Highway
2b	Replace Continuous Two-Way Left-Turn Lane with Restrictive Median
3a	Install Left-Turn Deceleration Lanes
3c	Install Continuous Two-Way Left-Turn Lane
3d	Install U-Turns as Alternative to Direct Left-Turns
3e	Install Jug-Handle and Eliminate Left Turns
6a	Install Frontage Road to Provide Access to Individual Parcels
6b	Locate/Relocate the Intersection of a Parallel Frontage Road and Cross Road Further from the Arterial Cross Road Intersection

2. Traffic Signal Spacing (Technique 1a)

The spacing of traffic signals, in terms of their frequency and uniformity, governs the performance of urban and suburban highways. It is one of the most important access management techniques. This is why Colorado, Florida, and New Jersey require long signal spacings (e.g. 2 mile) or minimum through band widths (e.g. 50 percent) along principal arterial roads.

Safety

Several studies have reported that accident rates (accidents per million VMT) rise as traffic signal density increases. An increase from two to four traffic signals per mile resulted in about a 40 percent increase in accidents along highways in Georgia and about a 150 percent increase along US 41 in Lee County, Florida. However, the safety impacts may be obscured in part by differing traffic volumes on intersecting roadways and by the use of vehicle-miles of travel for computing rates, rather than the accidents per million entering vehicles.

Travel Times

Each traffic signal per mile added to a roadway reduces speed about two to three mph. Using two traffic signals per mile as a base results in the following percentage increases in travel times as signal density increases. For example, travel time on a segment with four signals per mile would be about 16 percent greater than on a segment with two signals per mile.

Signals Per Mile	Percent Increase in Travel Times (Compared to 2 Signals Per Mile)
2.0	0
3.0	9
4.0	16
5.0	23
6.0	29
7.0	34
8.0	39

3. Unsignalized Access Spacing (Technique 1b)

Access points introduce conflicts and friction into the traffic stream. As stated in the 1994 AASHTO *Policy on Geometric Design of Highways and Streets*, "Driveways are, in effect, at-grade intersections .... The number of accidents is disproportionately higher at driveways than at other intersections; thus, their design and location merit special consideration."

It is increasingly recognized that spacing standards for unsignalized access points should complement those for signalized access. Potentially high-volume unsignalized access points should be placed where they conform to traffic signal progression requirements. On strategic and primary arterials, there is a basic policy decision of whether or not access should be provided entirely from other roads.

Safety

Many studies over the past 40 years have shown that accident rates rise with greater frequency of driveways and intersections. Each additional driveway increases accident potential. This finding was confirmed by a comprehensive safety analysis of accident information obtained from Delaware, Illinois, Michigan, New Jersey, Oregon, Texas, Virginia, and Wisconsin.

About 240 roadway segments, involving more than 37,500 accidents, were analyzed in detail. Accident rates were derived for various spacings and median types. The accident rate indices shown below were derived using 10 access points per mile as a base. (Access density is a measure of the total number of access points in both travel directions.) For example, a segment with 60 access points per mile would be expected to have an accident rate that is three times higher than a segment with 10 access points per mile. In general, each additional access point per mile increases the accident rate by about 4 percent.

Total Access Points Per Mile (Both Directions)	**Accident Rate Index**
10	1.0
20	1.4
30	1.8
40	2.1
50	2.5
60	3.0
70	3.5

Representative accident rates by access frequency, median type and traffic signal density are summarized in Table 3 for urban and suburban areas. Tables 4 and 5 show how accident rates rise as the total access points per mile (both signalized and unsignalized) increases in urban and rural areas, respectively, as a function of the median treatment. In urban and suburban areas, each access point (or driveway) added would increase the annual accident rate by 0.11 to 0.18 on undivided highways and by 0.09 to 0.13 on highways with TWLTLs or non-traversable medians. In rural areas, each point (or driveway) added would increase the annual accident rate by 0.07 on undivided highways and 0.02 on highways with TWLTLs or non-traversable medians.

Travel Times

Travel times along unsignalized multi-lane divided highways can be estimated using procedures set forth in the *1994 Highway Capacity Manual* (HCM). Speeds are estimated to be reduced by 0.25 mph for every access point up to a 10 mph reduction for 40 access points per mile. The HCM procedure is keyed to access points on one side of a highway, but access points on the opposite side of a highway may be included where they have a significant effect on traffic flow.

Table 3

Representative Accident Rates
(Accidents Per Million VMT)
By Access Density
Urban and Suburban Areas

Unsignalized Access Points Per Mile	**Signalized Access Points Per Mile**			
	. 2	**2.01-4.00**	**4.01-6.00**	**> 6**
. 20	2.6	3.9	4.8	6.0
20.01-40	3.0	5.6	6.9	8.1
40.01-60	3.4	6.9	8.2	9.1
>60	3.8	8.2	8.7	9.5
All	3.1	6.5	7.5	8.9

Table 4

Representative Accident Rates
(Accidents Per Million VMT)
By Type of Median - Urban and Suburban Areas

Total Access Points Per Mile (1)	**Median Type**		
	Undivided	**Two-WayLeft-Turn Lane**	**Non Traversable Median**
. 20	3.8	3.4	2.9
20.01-40	7.3	5.9	5.1
40.01-60	9.4	7.9	6.8
>60	10.6	9.2	8.2
All	9.0	6.9	5.6

(1) Includes both signalized and unsignalized access points.

Table 5

Representative Accident Rates
(Accidents Per Million VMT)
By Type of Median - Rural Areas

Total Access Points Per Mile [(1)]	**Median Type**		
	Undivided	**Two-WayLeft-Turn Lane**	**Non Traversable Median**
. 15	2.5	1.0	0.9
15.01-30	3.6	1.3	1.2
> 30	4.6	1.7	1.5
All	3.0	1.4	1.2

(1) Includes both signalized and unsignalized access points.

Curb Lane Impacts

Detailed analyses were made to estimate curb-lane impacts on through traffic resulting from cars turning right into driveways at 22 unsignalized locations in Connecticut, Illinois, New Jersey, and New York.

__Impacted Vehicles__. The percentage of through vehicles in the right (curb) lane that would be impacted at a single driveway increases as right-turn volumes increase as shown below.

Right-Turn Volume Entering Driveway (Vehicles Per Hour)	Percent of Through Vehicles Impacted
Less than or equal to 30	2.4
31 to 60	7.5
61 to 90	12.2
Over 90	21.8

__Influence Distances__. The influence distances were calculated adding driver perception-reaction distances and car lengths to the impact lengths. The percentages of right-lane through vehicles that would be influenced to or beyond an upstream driveway in a quarter-mile section were estimated for various right-turn volumes, driveway spacings, and posted speeds. The likely percentages of impacted vehicles that would extend to or beyond at least one driveway (upstream) per quarter mile (i.e., "spillback") for a 45 mph speed were as follows:

Right-Turn Volume Per Driveway (vph)	Unsignalized Access Spacing (Feet)				
	100	200	300	400	500
Less than or equal to 30	27.3	14.6	7.8	2.6	0.9
31-60	64.2	40.0	23.0	8.0	2.9
61-90	82.1	57.5	35.3	12.9	4.7
Over 90	96.1	80.1	55.5	22.1	8.3

This information may be used to identify the cumulative impact of decisions concerning driveway locations and unsignalized access spacing.

Right-Turn Lanes

Right-turn deceleration lanes should be provided wherever it is desired to keep the proportion of right-lane through vehicles impacted to a specified minimum. For arterial right-lane volumes of 250 to 800 vph, the percentage of through vehicles impacted was about 0.18 times the right-turn volume. This results in the following impacts that may provide a basis for decisions regarding provision of right-turn deceleration lanes:

Percent Right-Lane Through Vehicles Impacted	Right-Turn-In Volume (vph)
0	0
2	10
5	30
10	60
15	85
20	110

Criteria of 2 percent and 5 percent impacted suggest minimum right turn volumes of 10 vph and 30 vph, respectively. This range may be applicable in certain rural settings. Criteria of 15 percent and 20 percent impacted suggest a minimum of 85 vph and 110 vph, respectively. This range may be applicable in certain urban areas. The length of the deceleration lane is a function of the impact length and storage requirements.

Access Separation

Three factors influence the desired access separation distances -- safety, operations, and roadway access classification. Direct property access along strategic and principal arterials should be discouraged. However, where access must be provided, adequate spacing should be established to maintain safety and preserve movement.

"Spillback" is defined as a right-lane through vehicle that is influenced to or beyond the driveway upstream of the analysis driveway. It occurs when the influence length is greater than the driveway spacing minus the driveway width. The spillback rate represents the percentage of right-lane through vehicles that experience this occurrence.

The spillback rate should be kept to a level that is consistent with an arterial's function and desired safety and operations. Table 6 provides suggested access separation distances for spillback rates of 5, 10, 15, and 20 percent. For the lower speeds of 30 and 35 mph, access separation distances shown are based on the safety implications of driveway density. For roadways with a primary function of mobility, there should not be more than 20 to 30 connections per mile (both directions).

4. Corner Clearance (Technique 1c)

Corner clearances represent the minimum distances that should be required between intersections and driveways along arterial and collector streets. As stated in the AASHTO *Policy on Geometric Design of Highways and Streets*: "Driveways should not be situated within the functional boundary of at-grade intersections. This boundary would include the longitudinal limits of auxiliary lanes."

Table 6

Access Separation Distances (Feet) Based on Spillback Rate*

Posted Speed (mph)	Spillback Rate**			
	5%	10%	15%	20%
30	335	265 [a]	210 [b]	175 [c]
35	355	265 [a]	210 [b]	175 [c]
40	400	340	305	285
45	450	380	340	315
50	520	425	380	345
55	590	480	420	380

(a) Based on 20 driveways per mile.
(b) Based on 25 driveways per mile.
(c) Based on 30 driveways per mile.

* Based on an average of 30 to 60 right runs per driveway.

** Spillback occurs when a right-lane through vehicle is influenced to or beyond a driveway upstream of the analysis driveway.

The spillback rate represents the percentage of right-lane through vehicles experiencing this occurrence.

Corner clearance criteria assembled from various state, county, and city agencies showed values ranging from 16 to 325 feet.

Eight case studies of corner clearances were reviewed to illustrate current practices, problems and opportunities. These case studies indicated that (1) definition of corner clearance distances varied among locations; (2) distances ranged from two to 250 feet; (3) queuing or spillback across driveways was perceived as the most pervasive problem, making it difficult to turn left into or out of a driveway; (4) roadway widening to increase capacity sometimes reduces corner clearances; (5) placing driveways too close to intersections correlates with higher accident frequencies C sometimes up to half of all accidents involved are driveway-related; (6) corner clearances are limited by the property frontage available; (7) improving or retrofitting minimum corner driveway distances is not always practical, especially in built up areas.

The analyses suggested that adequate corner clearances can best be achieved where they are established before land subdivision and site development approval. Corrective actions include: (1) requiring property access from secondary roads; (2) locating driveways at the farthest edge of the property line away from the intersection; (3) consolidating driveways with adjacent properties; and (4) installing a raised median barrier on approaches to intersections to prevent left-turn movements.

5. Median Alternatives (Techniques 2a, 2b & 3c)

The basic choices for designing the roadway median are whether to install a continuous two-way left-turn lane or a non-traversable median on an undivided roadway, or to replace a two-way left-turn lane with a non-traversable median. These treatments improve traffic safety and operations by removing left turns from through travel lanes. Two-way left-turn lanes provide more ubiquitous access and maximize operational flexibility. Medians physically separate opposing traffic, limit access, clearly define conflicts, and provide better pedestrian refuge; their design requires adequate provision for left and U-turns to avoid concentrating movements at signalized intersections.

An extensive review of safety and operational experience and models provided guidelines for impact assessment.

Safety

The safety benefits reported in studies conducted since 1970 were as follows:

- Highway facilities with two-way left-turn lanes had accident rates that were overall about 38 percent less than experienced on undivided facilities (13 studies).

- Highway facilities with non-traversable medians had an overall accident rate of 3.3 per million VMT compared to about 5.6 per million VMT on undivided facilities (10 studies).

- Highway facilities with non-traversable medians had an overall accident rate of 5.2 per million VMT compared to 7.3 per million VMT on facilities with two-way left-turn lanes (11 studies).
- The estimated total accidents per mile per year -- based on an average of seven accident prediction models -- were as follows:

ADT	Accidents Per Mile Per Year		
	Undivided Highway	**Two-Way Left-Turn Lane**	**Non-traversable Median**
10,000	48	39	32
20,000	126	60	55
30,000	190	92	78
40,000	253	112	85

Operations

Several operations studies have indicated that removing left-turning vehicles from the through traffic lanes reduces delays whenever the number of through travel lanes is not reduced. Some 11 operations models developed over the past 15 years confirmed these findings.

Economic Impacts

The economic impacts of various median alternatives depend upon the extent that access is improved, restricted, or denied. The impacts to specific establishments also depend on the type of activity involved and on background economic conditions.

Where direct left turns are prohibited, some motorists will change their driving or shopping patterns to continue patronizing specific establishments. Some repetitive pass-by traffic will use well designed or conveniently located U-turn facilities. Impacts also will be reduced at locations where direct left-turn access is available. In some cases, retail sales may increase as overall mobility improves.

The maximum impacts resulting from median closures can be estimated by multiplying the number of left turns entering an establishment by the proportion of these turns that represents pass-by traffic. Typical proportions of this pass-by traffic are as follows:

- Service Station-Convenience Market 55%
- Small Retail (<50,000 sq. ft.) 55
- Fast Food Restaurant with DriveThrough Window 45
- Shopping Center (250,000 - 500,000 sq. ft.) 30
- Shopping Center (Over 500,000 sq. ft.) 20

Selecting a Median

Selecting a median alternative depends upon factors related to policy, land use, and traffic. These factors include: (1) the access management policy for and access class of the roadway under consideration; (2) the types and intensities of the adjacent land use; (3) the supporting street system and the opportunities for rerouting left turns; (4) existing driveway spacings; (5) existing geometric design and traffic control features (e.g. proximity of traffic signals and provisions for left turns); (6) traffic volumes, speeds, and accidents; and (7) costs associated with roadway widening and reconstruction.

6. Left-Turn Lanes (Technique 3a)

The treatment of left-turns is a major access management concern. Left turns at driveways and street intersections may be accommodated, prohibited, diverted, or separated depending upon specific circumstances.

Safety

A synthesis of safety experience indicates that the removal of left turns from through traffic lanes reduced accident rates about 50 percent (range was 18 to 77 percent).

Operations

Left turns in shared lanes may block through vehicles. The proportion of through vehicles blocked on approaches to signalized intersections is a function of the number of left turns per traffic signal cycle as shown below:

Left Turns Per Cycle	Proportion of Through Vehicles Blocked
1	0.25
2	0.40
3	0.60

The capacity of a shared lane might be 40 to 60 percent of that for a through lane under typical urban and suburban conditions. Thus, provision of left-turn lanes along a four-lane arterial would increase the number of effective travel lanes from about 1.5 to 2.0 lanes in each direction C a 33 percent gain in capacity.

Application of the *1994 Highway Capacity Manual* gives the following illustrative capacities for two- and four-lane roads at signalized intersections:

Condition	Capacity - Vehicles Per Hour Per Approach	
	Two-Lane Road	**Four-Lane Road**
No Left Turns	840	1,600
Shared Lane (50 to 150 Left Turns/Hour)	425-650	900 - 1,000
Exclusive Left-Turn Lanes	750-960	1,100 - 1,460

7. U-Turns as Alternatives to Direct Left Turns (Technique 3d)
U-turns reduce conflicts and improve safety. They make it possible to prohibit left-turns from driveway connections onto multi-lane highways and to eliminate traffic signals that would not fit into time-space (progression) patterns along arterial roads. When incorporated into intersection designs, they enable direct left-turns to be rerouted and signal phasing to be simplified.

Safety
U-turns result in a 20 percent accident rate reduction by eliminating direct left-turns from driveways and a 35 percent reduction when the U-turns are signalized. Roadways with wide medians and "directional" U-turn crossovers have about half of the accident rates of roads with TWLTLs.

Operations
U-turns, coupled with two-phase traffic signal control, result in about a 15 to 20 percent gain in capacity over conventional intersections with dual left-turn lanes and multi-phase traffic signal control.

A right-turn from a driveway followed by a U-turn can result in less travel time along heavily traveled roads than a direct left-turn exit when there is up to half a mile of additional travel.

Indirect U-turns may require a median width of 40 to 60 feet at intersections depending upon the types of vehicles involved. Narrower cross sections may be sufficient when there are few large trucks.

8. Access Separation at Interchanges (Technique 1d)
Freeway interchanges have become focal points of activity and have stimulated much roadside development in their environs. Although access is controlled within the freeway interchange area, there generally is little access control along the interchanging arterial roadways.

Separation distances reported by state agencies ranged from 100 to 700 feet in urban areas and 300 to 1000 feet in rural areas. Case studies reported separation distances of 120 to 1,050 feet. These distances are usually less than the access spacing needed to ensure good traffic signal progression and to provide adequate weaving and storage for left turns.

Desired access separation distances for free-flowing right turns from exit ramps should include the following components:

• Perception-Reaction Distance	100-150 feet
• Lane Transition	150-250 feet
• Left-Turn Storage	50 feet per left-turn per cycle
• Weaving Distance	800 feet, 2-lane arterials 1200 feet, 4-lane arterials 1600 feet, 6-lane arterials
• Distance to Centerline of Cross Street	40-50 feet

9. Frontage Roads (Techniques 6a and 6b)

Frontage roads reduce the frequency and severity of conflicts along the main travel lanes and permit direct access to abutting property. Along freeways and expressways, they can be integrated with interchange and ramping systems to alleviate congestion and to improve access. Frontage roads along arterials should be carefully designed to avoid increasing conflicts at intersections. Reverse frontage or "backage" roads with developments along each side may be desirable in developing areas. In all cases, arterial frontage roads must be carefully designed and located to protect arterial and cross road operations.

10. Policy Considerations

Several planning and policy implications emerged from the research. Some key findings follow:

- Comprehensive access management codes should indicate where access is allowed or denied for various classes of roads, specify allowable spacings for signalized and unsignalized connections, and set forth permit procedures and requirements. Codes may define or limit the application of specific techniques and establish procedures for an administering agency to use in removing access.

- There should be a sufficient network of supporting local and collector streets that provide direct access to adjacent developments. These secondary streets should connect to arterial streets at appropriate and well-spaced locations. They make it possible to minimize direct property access on major arterials.

- Access should be provided from strategic and primary arterials only when reasonable access cannot be provided from other roadways. In such cases, access should be limited to right turns wherever possible.

- Left-turn and cross egress should be well separated and placed at locations that fit into overall signal coordination patterns with high efficiency.

- Advance purchase of right-of-way and access rights is desirable. Access spacing standards (including corner clearance requirements) should be established in advance of actual development.

- Coordination of land use and transportation planning is essential. Zoning, subdivision, and access spacing requirements should be consistent. Better coordination of land use, interchange geometry, and arterial street operations are necessary to avoid "double loading" arterials and to minimize weaving movements and traffic congestion. Strategically placed supporting streets and frontage roads may play a major role in this effort.

- Wide medians that allow indirect U-turns in lieu of direct left turns should be considered for new arterials where space permits, since these medians improve safety and simplify intersection operations and signal timing/coordination.

- Any access control or management plan must be done on a route or system-wide basis to avoid transferring problems to upstream or downstream intersections.